Reconfigurable antenna in mm-waves based on stratified lens and sources array

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*Abstract***— This paper deals with radiation pattern reconfigurable antenna in millimetre wave range. The innovative antenna system is based on an inhomogeneous HMFE lens (Half Maxwell Fish Eye) fed by sources array. The number of fed sources and the lens allow to both control the radiation pattern and to achieve a good efficiency. The global antenna permits to have beam shaping capability without phase shifters. Directive and sectorial radiation patterns can be obtained for both on-axis and off-axis configurations.**

I. Introduction

Far field radiation control antennas are an interesting solution for wireless communication and radar in MM-waves range. For instance, short range and ''Stop and Go'' radars are studied to obtain beam shaping antennas for automotive cruise control radars [1]. To achieve a reconfigurable radiation pattern, active printed arrays are well suited thanks to an easy interconnexion between printed technology and active devices. But a low efficiency is often obtained because of microstrip-line losses in the mm-waves range. Moreover, in such frequency range, phase shifters and amplifiers are scarce and expensive.

In this paper, the authors propose a new antenna, without phase shifter, but combining a source array and a lens to both control the radiation pattern and achieve a high efficiency. For this innovative configuration, only switches allow to control the beam shaping. In our case, inhomogeneous lenses [2] have been investigated for this work but constant K lenses [3] could also be employed.

This paper is organized as follows. In section II is presented the Half Maxwell Fish Eye Lens (HMFE) on which we have been working for many years in IETR laboratory. Focusing and beam forming capabilities will be shown for this lens at 77 GHz. In section III, the beam shaping antenna principle based on HMFE lens and sources array is detailed. Simulation results are shown using CST Microwave Studio at 77 GHz. In section IV, an active prototype with a 60mm HMFE lens fed by a 4 multilayer printed patches array allow to validate the simulation results. Finally, conclusion and prospects are given to explain the future work.

II. Inhomogeneous HMFE Lens associated with a single feed

Inhomogeneous lenses have focusing and beam forming capabilities. In such lens, the refraction index n(r) inside the lens follows a radial distribution. The most known example is the 'Luneburg' lens [2], but we investigated, since a few years, another kind of inhomogeneous lens named Half Maxwell Fish Eye (HMFE) [4]. This lens is hemispherical and its refraction index law is given by:

$$n(r) = \frac{2}{1+r^2}$$, where r is the normalized radial position.

The dielectric constant inside the lens ranges between 1 (r = 1) and 4 (r = 0). To approximate the continuous gradient index law, several concentric homogeneous dielectric shells are assembled and their characteristics have been optimized [5, 6]. The radius and dielectric constant of shells are chosen to optimize the directivity when the lens is fed by only one source (Fig.1). It is known that if only one source feeds the HMFE lens, a directive pattern is achieved.

An experimental prototype has been manufactured using a 9-shells 60mm diameter HMFE lens fed by a WR10 open-ended waveguide. The measured radiation pattern in E plane is compared to the computed radiation pattern (mode matching technique) [7] at 77 GHz. For this antenna, a 28.5dB measured gain is achieved.

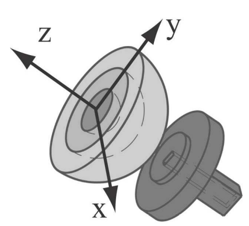

Fig.1: HMFE lens fed by a WR10 open-ended waveguide

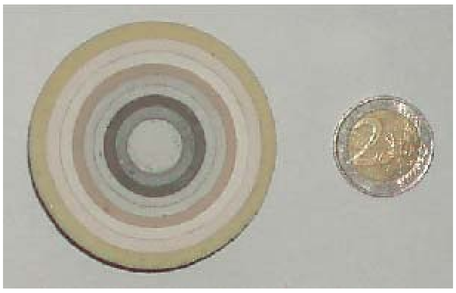

Fig.2: A 9-shell 60mm diameter HMFE lens

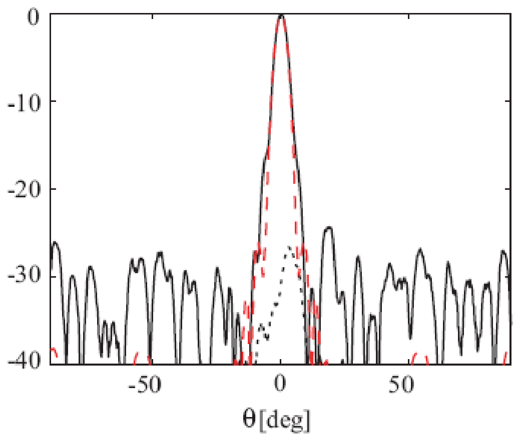

Fig.3: On-axis radiation pattern (E plane) at 77 GHz

In our case, the lens gradient index is approximated by assembling several concentric homogeneous dielectric shells. Then, the law is not perfect and a focal spot appears under the lens. Thus, if the feeder moves under the lens, it has been shown that it was possible to obtain beam scanning capability [8]. Measurements have been done (Fig. 4) at 77 GHz to show this capability in the H plane of the antenna. The 9-shell 60mm diameter HMFE lens is always fed by a WR10 open-ended waveguide. It is possible to steer the beam up to 12° when the feeder offset equals 5mm.

Let us then interest in the beam shaping capability if many sources are associated with the lens.

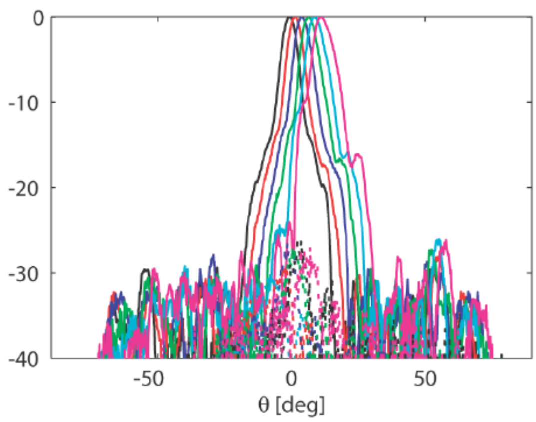

Fig.4: Off-axis radiation patterns (H plane) at 77 GHz

III. Inhomogeneous HMFE Lens associated with an array

For the reconfigurable antenna in W band (77 GHz), the 9-shells 60mm diameter HMFE lens is fed by 9 open-ended waveguides placed along the H plane. All simulations have been done using CST Microwave Studio at 77 GHz. If only one waveguide feeds the lens, a directive pattern is achieved with a plane wave at the lens output (Fig. 5b). If the lens is fed by the 9 waveguides, a sectorial beam is obtained (Fig. 5a). So, it becomes easy to reconfigure the antenna directivity changing only the alimented source number [9]. It is important to note that a sectorial radiation pattern is obtained without any phase shifter. It is a main advantage in millimeter waves, because these devices are often scarce and expensive.

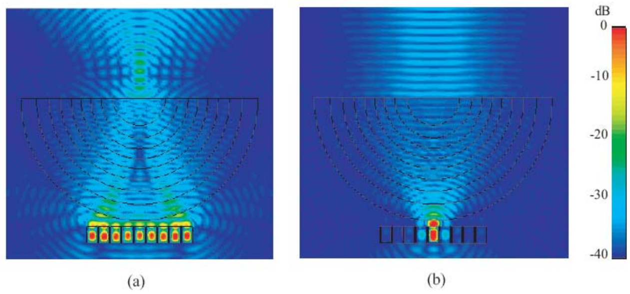

Fig.5: Reconfigurable radiation pattern antenna, (a) Sectorial beam if 9 sources feed the lens, (b) Directive beam if only on source feed the lens

We show (Fig. 6) the achieved radiation pattern for different configurations when 1, 3, 5, 7 or 9 waveguides feed the lens. The directivity can be modified between 20 and 31 dBi. In this case, for the E plane, the beamwidth pattern is always narrow thanks to the focusing capability of the lens. But it could be possible to shape the radiation pattern in both H and E planes simultaneously using a 2D sources array.

Thus, an easy reconfigurable antenna can be optimized in using only switches to control the number of active sources.

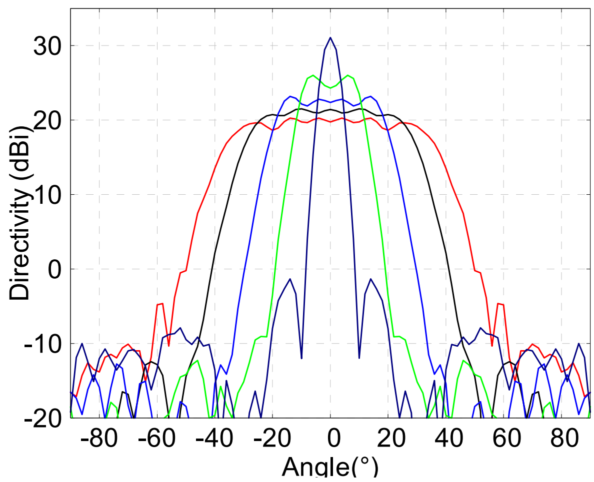

Fig.6: HMFE lens fed by respectively 1, 3, 5, 7 or 9 open-ended waveguides at 77 GHz.

Furthermore, this antenna system also allows having beam scanning properties. Indeed, for example, if a 3 sources group is considered and feeds the lens, the radiation pattern can scan if one moves the fed sources group (Fig. 7). An off-axis sectorial beam is shown because many sources feed the lens simultaneously (Fig. 8).

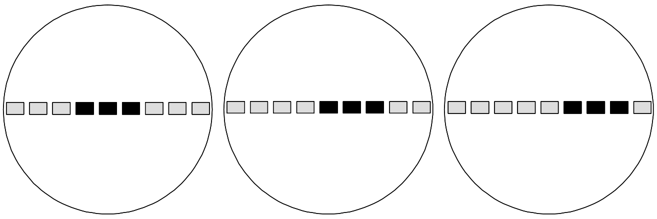

Fig.7: HMFE lens fed by a sources group which moves electronically under the lens.

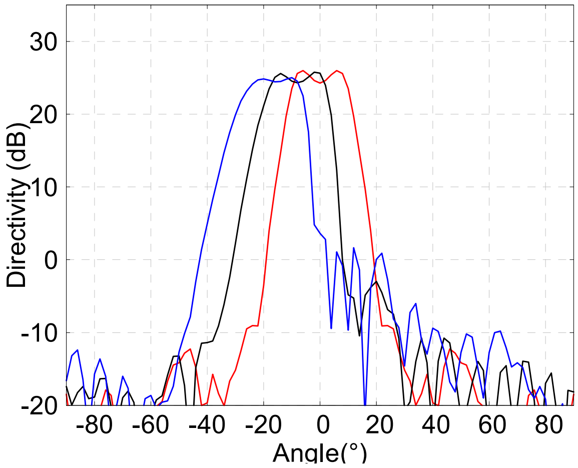

Fig.8: HMFE lens fed by a sources group which moves electronically under the lens – Radiation pattern for several configurations.

This beam shaping capability for lens and antenna array is experimentally validated at 24 GHz using an active system including switches as presented in the following section.

IV. Active prototype to reconfigure radiation pattern at 24 GHz

In this prototype, the active sources array is based on a multilayer printed antenna array [10] which allows separating radiating elements from active switch. In this configuration (Fig. 9), patches are printed on top substrate (RT Duroid 5880, h = 0.127mm) and lines on bottom substrate (Duroid RO3003, h=0.127mm). The patches are fed by microstrip lines via coupling slots which are engraved in a thick copper ground plane (h=0.2 mm). A four patches array has been manufactured with each patch fed via a switch (Fig. 10). It has been decided to use a FET transistor (NEC NE3210s1) to design a low noise amplifier switch. This device allows to obtain 4/5 dB gain for the active antenna.

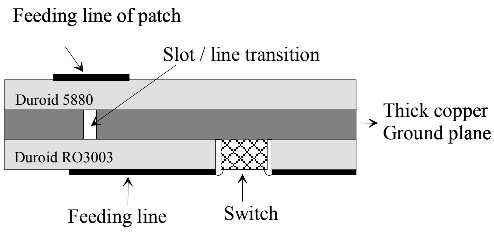

Fig. 9: Multilayer technology with active and radiating patches layers

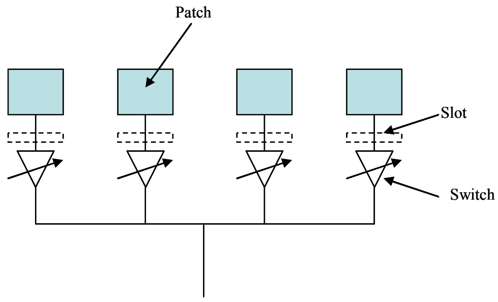

Fig. 10: Four patches multilayer printed array with active switches

The 9-shells 60mm diameter HMFE lens is fed by this active printed array. Radiation patterns at 24 GHz are simulated using CST Microwave Studio. For this simulation, a passive printed antenna array (without switches) is considered with the HMFE lens (Fig. 11). Two configurations are considered: two fed patches to obtain a directive pattern and four fed patches to obtain a sectorial one (Fig. 12). The measured radiation patterns are shown in Fig. 13 for the same cases.

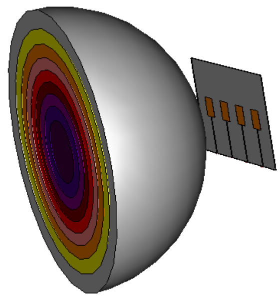

Fig. 11: Simulation of global system with feeders and lens.

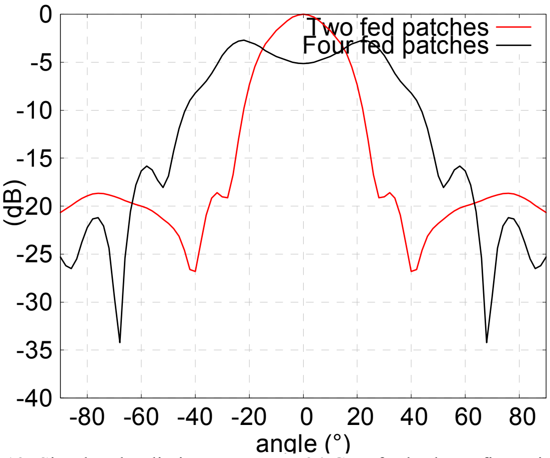

Fig. 12: Simulated radiation patterns at 24 GHz for both configurations

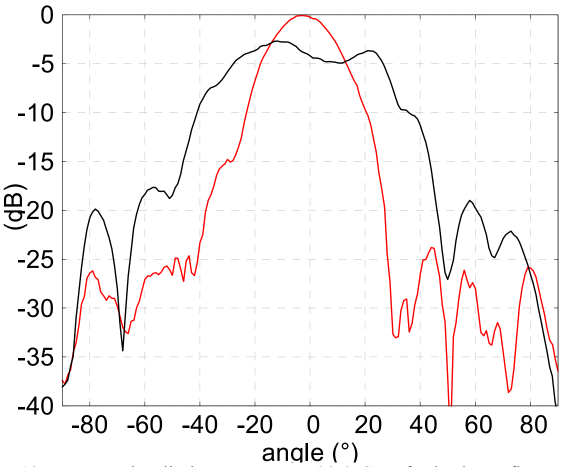

Fig. 13: Measured radiation patterns at 23.9 GHz for both configurations

A good agreement is obtained between simulated and measured half power beamwidths. Concerning gain characterization, the two configurations give respectively 22.5 dB and 19 dB. It is important to talk about the matching of the global antenna prototype. Indeed, the lens does not modify the matching of the active printed antenna array, because the gradient index inside the lens does not generate reflections toward the feed. Moreover, the feeding line network of the printed array has been optimized to match this antenna whatever the fed patches number [11].

V. Conclusions and Prospect

The authors have presented the inhomogeneous HMFE lens which allows to obtain high directive radiation pattern and gives the possibility to scan the beam if the feed moves under the lens. Then, the main work has concerned an innovative reconfigurable antenna based on inhomogeneous lens fed by sources array. It is possible to obtain shaping radiation capability without phase shifters up to millimeter waves range. If only one source feeds the lens, a high directive beam is obtained but if several sources feed this lens, a sectorial beam is achieved. The beamwidth of the sectorial radiation pattern depends on the fed patches number under the lens. An active prototype has been developed in 24 GHz band to experimentally validate the reconfigurable capability principle.

The choice of sources array technology to obtain good efficiency is currently under investigation. The final goal is to develop W band prototype. The printed technology introduces indeed losses in high frequencies. Studies have begun about Substrates Integrated Waveguide to design the array feeding line network.

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